Programme on Energy, Environment, Resources, and Sustainability (PEERS) – 1999/2000

Final Project Report

Assesment of fuel cell technology as a clean energy option for
Indian natural gas sector

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EXECUTIVE SUMMARY

Background:

The first fuel cell was built by Sir William Grove during 1839 and since the continuous research and development activities are going an in the developed countries. During 1960, fuel cells have been applied in Gemini and Apollo spacecraft for power generation. In the context of oil shock during 1970s and rising environmental concerns, attempts are being made to develop this technology through widespread demonstration projects across the world, particularly in North America and Japan.

The objective of this project is to provide a background in support of a clean and efficient power system such as fuel cell for the sustainability of our global energy resources in 21st century. Fuel cells are relatively new but a fast developing energy conversion technology with a unique combination of attractive features. The scope of study involves first hand knowledge of fuel cell technology and assessment of its suitability including possible time frame for early introduction of fuel cell based power for Indian natural gas sector particularly in Oil and Natural Gas Corporation Limited and Gas Authority of India Limited.

Research methodology adopted involves collection of secondly data from Internet and international journals regarding operational and commercialization experience of fuel cell plants around the world. Some primary data with respect to selection of potential sites for fuel cell applications in India have been collected from the field directly. Some operating fuel cell power plants (PAFC and MCFC) in North America were visited during 2nd phase of PEERS programme to acquire first hand information regarding operational experience and reliability of the technologies. Based upon all such data, assessment was made on fuel cell technology for Indian market segment on the basis of niche applications, technical evaluation and economic viability as well. Finally, an acceptable cost has been worked out to enable entry of fuel cell technology into Indian market.

The expected contribution from this assessment is undoubtedly far reaching including first hand evaluation of fuel cell technology for Indian environment, economi assessment of a new, more efficient but commercially immature technology at present cos and with projected cost as well. This will also generate possible options for diversificatio of corporate activities in hydrocarbon sector e.g. fuels supply for environment-friendl PEMFC vehicles.

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1.1 RATIONALE BEHIND THE STUDY :-

The concept of sustainable development implies meeting the needs of the present without compromising the ability of future generations to meet their needs. Development being a continuous process must not reach a dead end even in the situation, when the present resources are exhausted. Sustainability of any development process requires efficient and equitable use of existing resources. Such developments, while providing improved quality of human life must ensure protection of the earth and environment around us. Sustainable development by far remains the most important challenge for the humanity in the 21st century.

Sustainable development requires creation of new technologies, that are efficient and environment friendly, so that existing natural resources can be used optimally & judiciously. In this context, fuel cell technology is a clean and efficient power system, which is emerging as an energy option for this century. Since, about 80% of the global energy demand is met by fossil fuels e.g. coal, petroleum and natural gas and these resources are going to be exhausted in near future, it is envisaged that multi-fuel based fuel cells will play an important role in future energy scenario.

Fuel Cells: A sustainable energy option:-

There is a growing scientific consensus that increasing levels of greenhouse gas emissions are changing the climate of earth . The natural greenhouse gases include carbon dioxide, water vapour, nitrous oxide, methane etc among which CO_2 is the major constituents. Since, the beginning of the industrial revolution in 1764, burning of fossil fuels and the increased energy demand of fast growing world population have added greenhouse emissions to the environment. The concentration of carbon dioxide in the atmosphere has risen from 280 ppm to current level of 360 ppm during last 235 years and expected to exceed 600 ppm by the year 2100. Consequently, the average temperature of the earth has warmed up about 1^0 C since the mid-19th century. Based upon this scenario, the intergovernmental panel on climate change has concluded that the increase in greenhouse gases may be expected to cause a rise in the global warming between 1^0 C and 3.5^0 C by the end of 21st century. The effect of global warming has been predicted to be extreme weather, sea level rise and other social implications like health hazards for living beings.

While the link between climate and ecology remains uncertain, decisions made during the next ten years could affect generations to come . It is quite reasonable to suggest that the introduction of fuel cells into the energy and transportation sectors will have global implications. Reducing global use of depleting resources of petroleum, higher energy efficiency, transition to multi-fuel type energy systems and continued support for research in this direction are some of responsible steps for the purpose. For example, the introduction of fuel cells into the transportation sector will enhance fuel efficiency, decrease dependency on foreign oil and become an important technology to mitigate climate change. Fuel cell vehicles operating on natural gas or methanol result greenhouse gas emissions by 50% compared to internal combustion engines. In the future scenario, the combination of fuel cells and other renewable energy systems would nearly eliminate GHG emissions. The early transition to lower carbon based fuels will begin to create cleaner environment and a stronger national energy security.

1.2 SCOPE OF THE PROJECT :-

To assess the suitability and a possible time frame for the implementation of fuel cell based power and heat systems for Indian natural gas sector, particularly in Oil and Natural Gas Corporation Limited (ONGC) and Gas Authority of India Limited (GAIL).

1.3 METHODOLOGY :-

Methodology involves the following steps for systematic compilation of disseminated data.

I. Status of fuel cell technologies.
II. Assessment of fuel cell technologies.
III. Selection of potential sites for fuel cell application.

2.1 BASIC CONCEPT :

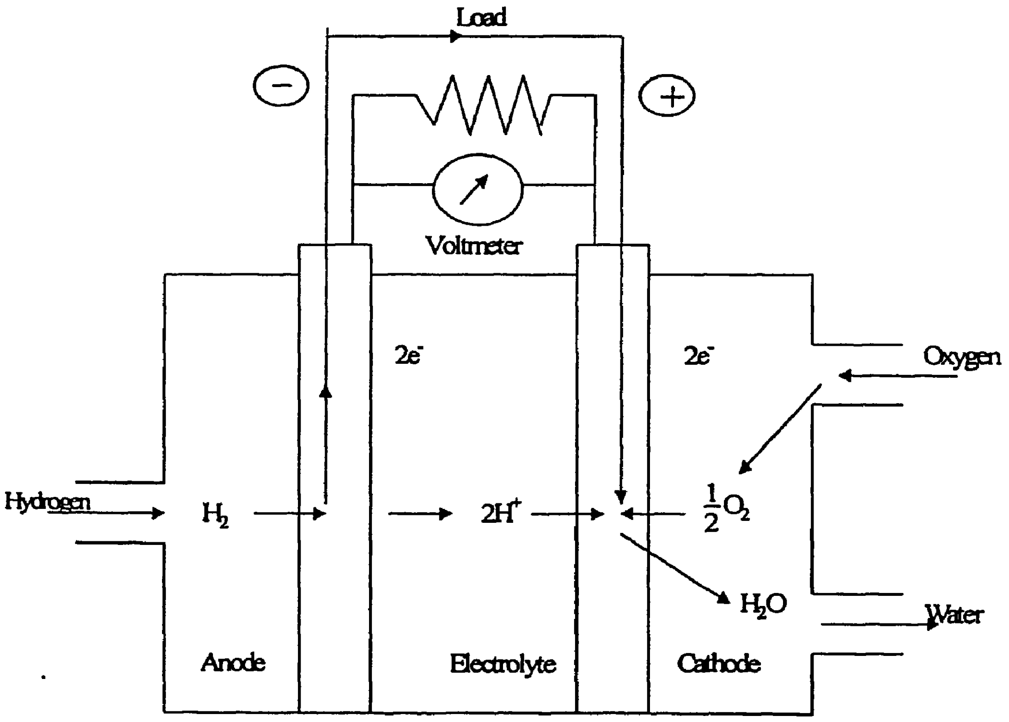
- Fuel Cells are electrochemical energy conversion devices that can continuously Transform the chemical energy of a fuel and oxidant to electrical energy by an Isothermal process involving an essentially invariant electrolyte system.

- Fuel Cell functions in the reverse of electrolysis process. Primarily, hydrogen and Oxygen is combined to form water and electricity.

- In construction, a fuel cell is similar to a battery. It contains an electrolyte in between the two electrodes (anode and cathode). The electrolyte, in most cases are not kept free, but retained in a porous, chemically inert structure known as tile or matrix.

2.2 OPERATING PRINCIPLE:

At the anode, the fuel is electrochemically oxidized to give up electrons, which are conducted through an external electrical circuit to the cathode, where the electrons combine with the oxidant and reduce the oxidant. The loop is closed by the ions which are conducted through the electrolyte from one electrode to the other. The direction of the ion conduction depends upon the type of fuel cell. Each electrode is in contact with a current collector which picks up or delivers the electrons which flow through the external circuit and load.



Schematic of an acid electrolyte fuel cell

Operating principle of an acid electrolyte fuel cell:

- Hydrogen gas passes through current collector and diffuses through the Anode.
- When come in contact with electrolyte (acid) in presence of anode catalyst, electrons split from hydrogen and move out through current collector to pass through the electrical load. Hydrogen is now in the form of hydrogen proton (H^+).

- Hydrogen proton moves through the electrolyte to the cathode. Electron stream reaches at cathode through the load. Oxygen is diffused into the cathode.
- The hydrogen proton, the electron, and the oxygen combine to form water.

2.3 TYPES OF FUEL CELL:

Their electrolyte types i.e. phosphoric acid; molten carbonate, alkaline, solid oxide and solid polymer distinguish the fuel cells.

2.3.1 The Phosphoric Acid Fuel Cell (PAFC) is called the first generation fuel cell, which has already been commercialized in North America, Japan and Europe. The system was originally developed by United Technologies Corporation (UTC) in the US for military operation using hydrocarbon fuels. PAFC power plants have been extensively field-tested and are already commercially available in 200 KW size only. The catalyst here is platinum, which is finely deposited onto high surface area carbon black particle substrate. As the electrolyte, concentrated phosphoric acid (97% pure) is used. Hydrophobic polymers such as Teflon is mixed with the platinized carbon during electrode fabrication as bonding and wet proofing agent, so as to increase the water repelling capacity of electrode and to form a porous carbon substrate. The porous carbon paper provides structural support to electrodes. This composite structure forms as stable three-phase interface in the fuel cell; with H_3PO_4 electrolyte on one side and the reactant gas environment on the other side of the carbon paper. The electrolyte phosphoric acid is retained in a porous solid structure known as matrix, made from phenolic fiber bonded with a phenolic resin or micron size silicon carbide and provides the proton (hydrogen ion

H^+) transfer medium. Hydrogen ion is the conduction ion from anode to cathode within the cell. The main problem in PAFC is electrode poisoning by carbon monoxide. The efficiency achieved for this type of fuel cell is upto 40-45% with operating temperature 180-210 degree Celsius. Electro-chemical reactions are as follows:

Anode: $H_2 \longrightarrow 2H^+ + 2e^-$
Cathode: $1/2\ O_2 + 2H^+ + 2e^- \longrightarrow H_2O$

Cell: $H_2 + 1/2O_2 \longrightarrow H_2O$

2.3.2 The Molten Carbonate Fuel Cell (MCFC) is called as the second-generation fuel cell technology. It is the most likely candidate for commercialization after Phosphoric Acid Fuel Cell. The state of the art cells are made of porous nickel anodes and porous lithiated nickel oxide cathode. The eutectic mixture of 38 mol% K2CO$_3$ and 62 mol% Li_2CO_3 is used as the electrolyte. The electrolyte retainer i.e. tiles or matrix is made from lithium aluminate due to its better tolerance and durability limits. The salts are liquid and ionized at the cell operating temperature of 650^0 – 700°C and provide carbonate ions for ionic transport. Carbon monoxide a poison for low temperature acid and alkali fuel cells, is a fuel constituent in the molten carbonate fuel cell. This decreases the required fuel processing and favours a greater range of options for fuel source, including integration with a coal gasifier. Waste heat at 650^0C can be utilized in a bottoming sub-cycle for electric power generation or process heat. The main problems in this cell are cathode dissolution, anode creeping, matrix strength, CO_2 recycling, anode poisoning by sulphur etc. Natural gas based internally reformed fuel cell plant in the order of 1to10 MW is of interest to ONGC. The efficiency of such plants can be achieved upto 90% with waste heat recovery system and 50-60% without waste heat recovery. The electro-chemical reactions are:

Anode: $H_2 + CO_3^{2-} \longrightarrow H_2O + CO_2 + 2e^-$
Cathode: $1/2O_2 + CO_2 + 2e^- \longrightarrow CO_3^{2-}$

Cell: $H_2 + 1/2O_2 + CO_2 \longrightarrow H_2O + CO_2$

The electrolyte retainer i.e. tile is held in between the two stainless steel cell housings, that form the anode and cathode cavities. The holding force maintains low-resistance contacts between the electrodes and the stainless steel current collectors and causes the housing to bite into the electrolyte tile, forming a wet seal that prevents leakage of fuel from the mode chamber and oxidant from the cathode chamber.

In a stack of several cells the cell separator must be able to withstand both the high-humidity reducing environment of the anode and the oxidizing environment of the cathode.

Carbon dioxide and oxygen diffuse from the bulk gas through the pores of the cathode to a reactions site at the electrode/electrolyte interface where they react according to

$CO_2 + ½ O_2 = CO_3^{2-}$

The cathode is 70-80% porous NiO with a mean pore size of about 10 micron, formed by oxidation of sintered nickel at operating temperature. The carbonate ion (CO_3^{-2}) is conducted through the liquid electrolyte, a mixture of alkali carbonates (commonly 62 mol % Li_2CO_3, balance K_2CO_3 i.e. 47:53 wt% respectively) molten at cell operating temperature. The electrolyte is held in place by inert $LiAlO_2$ particles to form the electrolyte tile ($LiAlO_2$:Li_2CO_3:K_2CO_3::40:28:32 wt basis). Since ohmic loss is a function of tile thickness, tiles are kept as thin as possible, 1.0 to 2.5 mm in current cells.

At the anode/electrolyte interface, carbonate ions react according to

$H_2 + CO_3^{2-} = H_2O + CO_2 + 2e^-$

and the external electrical circuit is complete.

The anode is sintered nickel about 60-70% porous with a 5micron mean pore size. The products, H_2O and CO_2 diffuse out of the cell through the porous anode into the gas stream. The overall chemical reaction in the molten carbonate fuel cell is

$H_2 + ½ O_2 = H_2O(g)$ + heat

Natural gas based MCFC power plants is said to be the future option of energy by the year 2002.

2.3.3 The Solid Oxide Fuel Cell (SOFC) system is the third generation fuel cell technology. It uses yttrium stabilized zirconia ($Zr_{0.9}\ Y_{0.1}\ O_{1.95}$) as its electrolyte. At cell operating temperature (1000°C), the electrolyte remains in solid form but anion vacancies created by introduction of aliovalent3+ ions on the Zr^{4+} sites produce an oxygen ion conductor. This ion moves to anode through the electrolyte and react with hydrogen or carbon monoxide to form water vapor and carbon monoxide respectively. At the same time, the electrons are released and move out through the electrical load, Since the electrolyte is solid, the electrolyte management problems associated with other type of fuel cells are eliminated. The higher temperature operation allows in situ reforming of hydrocarbon fuels and so fuel conversion efficiency can approach 60%. The state of the art of anode is nickel coated zirconia cermet and that of cathode is lanthanum magnate ($LaMnO_3$). Calcium stabilized zirconia being used as support material and magnesium doped lanthanum chromate ($Mg\text{-}LaCrO_4$) as the interconnection

material. Nickel plate is used as the current collector. The efficiency of such fuel cell is of the order of 60-65%.The chemical reactions are:

Anode: $H_2 + O^{2-} \text{---------------} \rightarrow H_2O + 2e^-$

Cathode $\frac{1}{2} O_2 + 2e^- \text{------------} \rightarrow O^{2-}$

Cell: $H_2 + 1/2\ O_2 \text{------------} \rightarrow H_2O$

2.3.4 The Alkaline Fuel Cell (AFC) is a low temperature fuel cell operated at 60^0-120°C. The limitation of this cell is that they need only pure hydrogen and oxygen. Any carbon monoxide (CO) or carbon dioxide (CO_2) present in the fuel reacts with the electrolyte (KOH) to form the carbonate salts. Pure hydrogen requirement affect the industrial use of this fuel cell, as carbon dioxide (CO_2) removal from the syngas / reformer product gas is difficult and is a costly process. When pure hydrogen is fed, it gives the highest potential and power output to weight ratio among fuel cells, which made it possible to use in the Apollo and Columbia space flights. In alkaline fuel cells, strong alkali (concentrated KOH) is used as electrolyte, which provides the hydroxyl ion $(OH)^-$ as transport medium. The anode catalyst is the dispersed platinum powder in a wet- proofing material like Teflon. When air is used as oxidant, non- noble material can be used as cathode. The waste heat product is of low quality, so have negligible importance for practical use. The product water is in liquid form, hence needs a special arrangement for water removal. The efficiency can be achieved ranging 35% to 40% in AFC. The chemical reactions are as follows.

Anode: $H_2 + 2(OH)^- \text{----------} \rightarrow 2H_2O + 2O^-$

Cathode: $\frac{1}{2} O2 + H_2O + 2e^- \text{-----} \rightarrow 2(OH)^-$

Cell : $H2 + 1/2\ O_2 \text{----------} \rightarrow H_2O$

2.3.5 The Solid Polymer Electrolyte Fuel Cell (SPEFC) uses an ion exchange membrane as the electrolyte. It can use the air and reformed fuel as the hydrogen source. A critical feature of this cell is that the membrane must be kept at just the right moisture content, so that the ionic transport across it can proceed while the contact point between the membrane and the electrolyte is maintained but not flooded. The electrode active material in these type of fuel cells are unsupported noble material like platinum, palladium. The product water / waste heat is of practical no use because of its lower grade (available at a temperature less than 100°C).The fuel cell has application mostly in automobiles. The reactions are:

Anode : H_2 --------------------→ $2H^+ + 2e^-$

Cathode: $\frac{1}{2} O_2 + 2H^+ + 2e^-$ ----------→H_2O

Cell: $H_2 + 1/2\ O_2$ -----------→H_2O

OUTLINE OF MAJOR FUEL CELLS :-

Features	PAFC	MCFC	SOFC
Generation	1st	2nd	3rd
Electrolyte	Phosphate acid	Carbonate	Solid oxide
Carrier of charge in electrolyte	H^+	CO_3^{--}	O^{--}
Operating temperature	200°C	600°C-700°C	1000°C
Fuel used	H_2, Reformed gas	H_2, CO, HC, Reformed gas of hydrogen	H_2, CO, HC, reformed gas of hydrogen
Power generation efficiency	40-45%	50%-60%	55%-65%
Other features	Commercially available	Wide range of fuel, Internal reform possible	Wide range of fuel internal reform possible

2.4 COMPARISON WITH BATTERY :

Unlike a battery, a fuel cell does not rundown after a certain period (as in primary Batteries) nor does it requires recharging (like secondary batteries) it will continue to operate as long as both fuel and an oxidant are supplied to the electrodes. In battery, the electrodes are charged chemically as the reactions occur and must be restored (a secondary battery) or simply used up (primary batteries). Fuel Cell electrodes are not used up in the reaction throughout its life. Also, unlike batteries, the fuel and oxidant are fed continuously to the fuel cell and theoretically there is no decrease in power output as the fuel composition and working environment remains unchanged.

Fuel cells act like integrated energy conversion devices. Fuel Cells produce Electricity by process of galvanic oxidation of the fuel and oxidant like common storage batteries and require continuous feed of sufficient fuel like internal combustion engines to drain desired output.

2.5 ADVANTAGES OF FUEL CELLS

2.5.1 Environment Acceptability:

* Acoustic emissions: Acoustic emissions strongly interfere with our ability to Operate under ordinary conditions. Since, the processes that take place in a fuel cell are electrochemical, ideally there should be no moving parts to generate noise and vibration. In practice, however, pumps, blowers, transformers, and other auxiliary devices are required in any system whose output exceeds 1 kW. In spite of this limitation, large fuel cell power units operate much more quietly and smoothly than any other power-generating devices.

* Chemical emissions : The fuel cell is not a combustion device, emissions such as NO_x, CO and unburnt hydrocarbons are not a serious problem. SO_x emissions are not a problem because the sulphur content of the fuel stream to the power plant must be reduced to attain long fuel cell life.

Table I Comparison of Power Plant Emissions (Kg./MWH)

Contaminant	Types of power plant			FCG-1 fuel Cell	EPA limits
	Gas–Fired	Oil-Fired	Coal-Fired		
SO_x	-	3.35	4.95	0.000 046	1.24
NO_x	0.89	1.25	2.89	0.031	0.464
Particulate	0.45	0.42	0.41	0.000 0046	0.155

- Thermal Emission: Since fuel cells are generally more efficient than Carnot limited thermo-mechanical power generators, especially in small units, they produce proportionally less waste heat. Small amounts of heat would be produced even if the fuel cell system did not have a separate fuel processing subsystem to generate hydrogen from a fossil fuel. When the waste heat, which is generated, is not utilized for auxiliary processes or on-site heating, it can normally be dumped directly into the air. Hence, water requirement for fuel cell operation is very low.

- Aesthetics or Visual Emission: "Visual Emission" is something that must be considered with any dispersed power unit, which might be used in a high property value area covered by zoning laws. Although the flow diagram of the fuel processing subsystem of a fuel cell generating station may tend to resemble a miniature refinery, there is no need for high smokestacks or obvious cooling towers beyond those in sizes resembling air-conditioning ducts, it should be possible to enclose the low profile subsystems within the basements of downtown buildings or under streets, as is being proposed for urban use in Japan.

2.5.2 Modularity

- A single fuel cell normally generates power at approximately 0.5 to 1 Volt DC and can be connected in series and / or parallel to get desired voltage output. The current is proportional to the cell area of single cell. The range of sizes, the modularity, and the load following capability make the fuel cell system an attractive candidate for power generation in a variety of applications.

- With modular design fuel cell efficiency is independent of size: small units can operate as efficiently as large one. Efficiency is relatively constant over a wide range of load.

2.5.3 Locational Flexibility:

Owing to the potentially modular construction of a fuel cell power plant, the amount of land required for the installation of a single unit may be relatively small. For example, the IFC 11-MW utility design was intended to occupy about 0.5 ha. The unit was also intended to be independent of a water supply. These characteristics, together with very low environmental impact and low maintenance requirements, should permit fuel cell power plants to be located in, relatively accessible sites which otherwise might prove to be unsuitable for conventional generation units. In addition, its "neighborliness" and high level of safety will allow it to be sited close to the point of use (e.g., in urban areas), where its waste heat may be used in cogeneration applications.

2.5.4 Reliability:

The U.S. aerospace program has proved the reliability of fuel cells for steady, uninterrupted power generation. Design reliabilities of greater than 95% have been achieved consistently under the stringent conditions of space flight. No fuel cell battery in NASA's program has yet failed (the often quoted failure on board Apollo 13 in April 1970 was that of a cryogenic oxygen tank, not a fuel cell). The design reliabilities (mean time to failure) required for most terrestrial uses are lower than those needed for man-qualified aerospace applications. However, terrestrial units require reliability during much longer total operating periods. It is expected that the first generation of commercial fuel cell power generation systems will have an on-stream availability of about 90%. Ultimately, fuel cell plants can have on-stream availability of 89-90%, values which are currently achieved in conventional hydrogen plants. It is interesting that in the 4.5MW U.S. built PAFC demonstration plants and their 1 MW Japanese counterparts, the fuel cell stacks have proven to be more reliable than the conventional balance of plant.

The high reliability of a fuel cell system will largely result from the modularity of the stacks and stack components, but should also be attributable to their lack of highly stressed moving parts operating under extreme conditions and to their ease of maintenance. Because the modules are repetitive, any problems which arise should be similar instead of one of a kind.

2.5.5 Safety:

Fuel cells certainly are as safe as coal, oil and natural gas burning central power stations, and they should be safer than nuclear power plants, because of the possibility of disaster & the latter resulting from systems or materials failure, neglect, and more particularly, sabotage or acts or war. In this connection, distribution systems using dispersed power generation will always be safer and inherently more reliable than those using centralized generation. Compared to other power generation systems operating on natural gas, fuel cell systems are obviously safer.

2.5.6 Fuel Flexibility:

As the fuel cells basically need hydrogen as its fuel and air as its oxidant, it is possible to use the same fuel cell stack with variety of fuel sources, with suitable fuel processors. Fuel processors for variety of raw fuels are available and can be used in connection with a fuel cell with a little modification. Various fuel sources like natural gas, coal, biomass, methanol, ethanol etc. can be used to extract hydrogen, which is the basic fuel of fuel cell plant.

2.5.7 Part Load Capability:

Conventional heat engines operate efficiently at full load and show a rapid falloff in efficiency at part load. In contrast, the voltage of a fuel cell, like that of a battery, is higher at part load than at full load. However, as stressed earlier, in most cases the characteristics of the fuel cell stack itself partly reflect those of the overall system, particularly when that system includes a fuel processor (e.g. a steam reformer and its associated subsystems). The latter tends to have a lower efficiency at part load, due to heat transfer losses and parasitic power requirements. Consequently, the overall efficiency of a fuel cell unit incorporating a fuel processor tends to be approximately independent of load, but may start to fall off at loads of less than 25-40% of full load.

2.5.8 Efficiency:

Since, the electrochemical transformation is isothermal, the fuel cell directly uses the available free energy in the fuel at its operating temperature. Thus, it is not

Carnot-cycle limited and can yield a high fuel to power conversion efficiency. Another aspect of high efficiency of fuel cells is that, it bypasses the intermediate thermal to mechanical energy conversion process. Fuel cells are inherently more efficient than conventional power generation devices.

2.6 FUELS :-

Fuel cells use hydrogen as the anode fuel and air as the cathode oxidant. High temperature fuel cells (MCFC & SOFC) can use CO as fuel too. Hydrogen is not available as a free gas in the nature but is a major constituent in the hydrocarbons. Therefore, fuel cells are accompanied with a fuel processor than can generate either hydrogen or syngas (mixture of hydrogen and carbon monoxide) at the site, which is the most economic way of hydrogen supply. Syngas can be generated by steam reforming of natural gas /light hydrocarbons/Methanol. Other feed stocks such as coal gas, biogas, landfill gas, naphtha, distillate and heavy oils can also be considered after selecting a suitable reforming process.

CHARACTERISTICS OF POTENTIAL FUELS FOR FUEL CELL VEHICLES

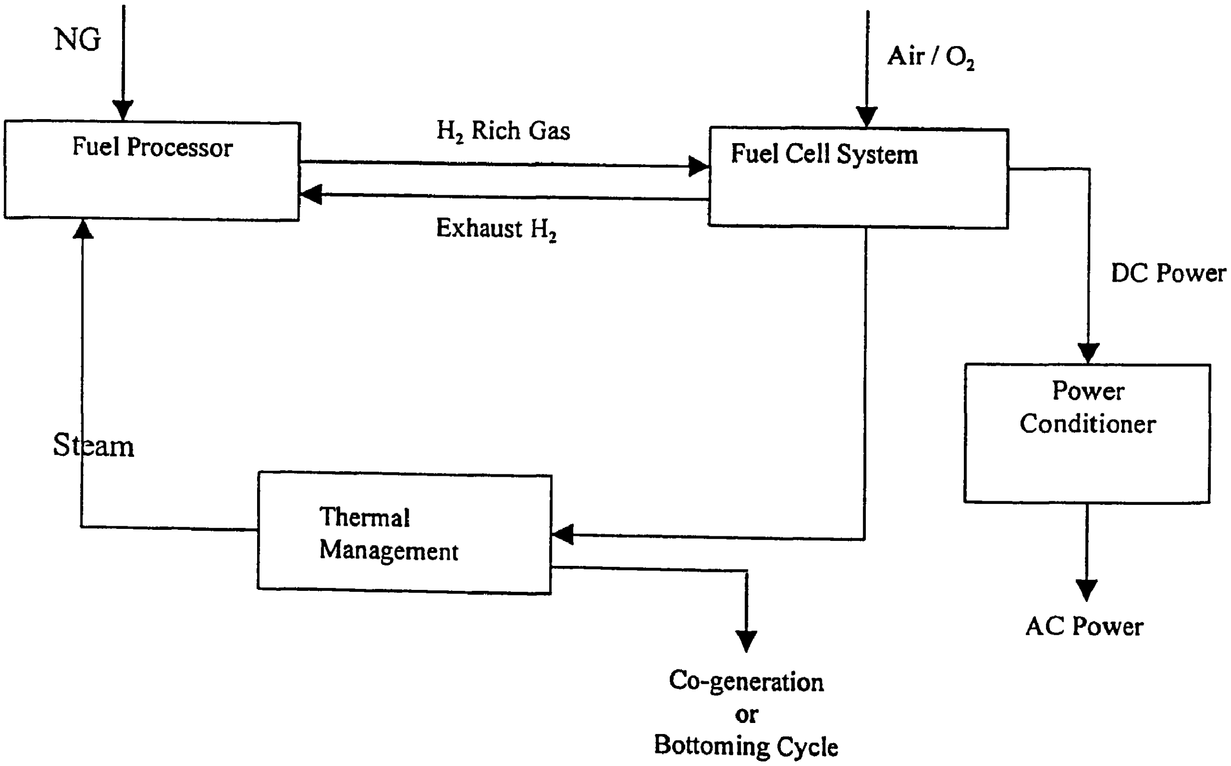
Sl.No	*Fuel Name*	*Production*	*Safety*	*Environmental Attributes*
1.	Reformulated gasoline (RFG)	From crude oil	Low flash point	Reduction in greenhouse gases
2.	Methanol (M1000)	From natural gas	Toxic, invisible flame	GHG emissions
3.	Ethanol (E-100)	From biomas	Less toxic	Zero CO_2 emission
4.	H_2	Coal, CNG or methane	Invisible Flame	Lower emission
.5	CNG	From natural gas or coal	Low flash point	NO_X emission

2.7 FUEL CELL POWER PLANT/SYSTEM

The fuel cell system consists of a fuel processor, a fuel cell, a power conditioner, and optional co-generation or bottoming cycles schemes, depending upon application. A hydrocarbon fuel (Natural gas, mined coal, solid waste, refined petroleum products or residues, synthetic natural gas, naphtha, methanol etc.), steam, and heat recycled from the fuel cell section are fed into the fuel processor to generate a hydrogen rich gas . The fuel processor could be a reformer, a gasifier or a hydro processor, depending on the hydrocarbon fuel used. The hydrogen rich mixture is then fed to the anode side of the fuel cell power section, formed by fuel cells connected electrically in series to generate the desired voltage. The d. c. power obtained is then processed by the power conditioner to produce the a. c. power to meet the user requirement.

If the fuel cell is located on-site (at the point where the electricity will be used), system efficiency can be greatly improved by co-generating electricity and the steam .

FUEL CELL POWER PLANT :-



A typical fuel cell produces less than one volt D.C., but the current is high (of the order of hundreds of amperes per square feet of electrode area). Practical voltage level is obtained by connecting several fuel cells in series which is commonly known as "Cell Stacks". Use of inverter slightly lowers the overall electrical output but increases the usefulness of electricity to a large extent. Removal of catalyst poisoning gases is utmost necessity for all type of fuel cells.

3.1 NATIONAL STATUS

In India ,the research on MCFC started since 1987 and a few achievements has already come out. Central Electrochemical Research Institute (CECRI), Karaikudi have done some single cell studies for MCFC.

TERI, New Delhi is developing an MCFC stack is planning a 5/10 KW stalk and also planning to develop a 100KW MCFC stack by 2002. In India, TERI expects laboratory scale stacks to cost about Rs.5-6 lakhs/KW with reduction in cost on increasing manufacturing & further optimization . BHEL did some developmental work as well . Recently, BHEL, Hyderabad has imported a 200KW PAFC power plant from M/S ONSI Corporation , USA for power and heat generation as a demonstration plant and it is supposed to be the first fuel cell plant in our country.

3.2 INTERNATIONAL STATUS OF FUEL CELL TECHNOLOGIES.

I. The companies/groups dealing with fuel cell products :

The following companies offer a variety of fuel cell powered products.

i. M/s ONSI corporation, 195 Governor's Highway PB-739, South Windsor, Connecticut -06074 USA

ii. M/s Fuel Cell Energy Incl., 3 Great Pasture Road, Danbury, Connecticut - 06813 USA

iii. M/s M-C power corporation, 8040 S. Madison Street, Burr Ridge, Illinois - 60521 USA

iv. M/s Westinghouse Science & Technology Centre, 1310 Beulah Road, Pittsburgh, PA - 15235 - 5098 USA

v. M/s Daimler - Benz in collaboration with M/s Ballard Power System, Vancouver, Canada

Now let us list out the type of fuel cell, size of systems & projected cost of the products dealt by some of these groups.

Groups	Type of Fuel Cell	Fuel used	System Size	Projected Cost in USD/KW	Application	Status of Technology	Location of Installations
ONSI	PAFC	Natural Gas or Propane	200 KW	1475	Power & Heat	Commercialized	170 Power plants in 13 Countries
ERC	MCFC	Natural Gas or Coal	2 MW	1100	Co-generation	Close to commercialization	Santa Clara, California
M-C Power	MCFC	Natural Gas	250 KW	N/A	Co-generation	Demonstration programmes	Sandiego, California
Westing House	SOFC	Natural Gas	25 KW	1500	Co-generation	Development stage	Netherlands
Ballards	PEMFC	Methanol	250 KW	1500	Automobiles (city transit bus & cars)	Close to commercialization	Chicago, Vancouver

3.3 DEMONSTRATION / COMMERCIALIZATION EXPERIENCE :

i. PHOSPHORIC ACID FUEL CELLS:

(a) In Japan :

Japanese gas companies have taken keen interest in the development of PAFC in 50 - 200 KW range. Initially, Fuji Electric, Japan commercialized PAFC by manufacturing 50 KW & 100 KW systems. Later on, Toshiba & Mitsubishi supplied 200 KW systems to Osaka Gas Company. Subsequently, Fuji Electric & Toshiba manufactured 500 KW & 1MW system respectively and supplied to various gas companies. Presently, a Japanese gas company has setup a 12 MW PAFC power plant, which is the largest fuel cell plant in the world till date.

(b) In USA :

Similarly, on the basis of Japanese experience, ONSI, a US company started manufacturing power plants since 1991. The largest running unit till date has recorded

40,000 hours of successful operation. PC 25A & PC 25C (modified version) model of ONSI has already been commercialized .

ONSI PC 25 fuel cell operates on fuel like natural gas, propane, light naphtha & waste gas from waste water treatment plant besides hydrogen. The electrical configurations include both 60 & 50 Hz frequency, either grid - connected or stand alone mode. The product heat from the fuel cell has been used for domestic hot water, space heating, and to drive absorption air conditioner. Durability and reliability statistics are encouraging. Individual power plants have operated for more than four years on continuous basis. Remote Control & Diagnostics have been used to avoid shutdown and to facilitate maintenance actions.

The PC 25 is designed and fabricated in accordance with standards of ANSI. Improvement incorporated in the PC 25 C model include a high power density cell stack, an inverter of reduced size and weight, smaller fuel processor, compact heat exchanger and improved control system.

ONSI PC 25 Fuel Cell Power Plant Experience :

In order to evaluate the performance of existing fuel cell and asses economic impact, seven numbers fuel cell power plants in North America were identified . Locations are as follows :

1. St. Vincents Hospital, Staten Island, New York.
2. Rochester Institute of Technology, Rochester, New York.
3. Paul Riefter Concrete Company, Hamburg, New York.
4. A Luxury Hotel in Irvine, California.
5. Food Processing Plant in Buena Park, California.
6. Medical Centre in Anaheim, California
7. Office of Consumers Gas Company, Toronto, Canada

From operation of these plants the following data were obtained.

1. Fuel Cell availability was 86.7% in comparison with 84.8% for GTs. By proper management availability can be increased upto 93.2%.
2. Mean time between outages (MTBO) for the group of seven fuel cells was 55 days, whereas MTBO for similar range of engine driven co-generator is 12 days only.

The reason for 30 outages were problems in the sub-systems like water treatment, thermal management, power distribution & ancillary cooling system.

The observations made on performance of these power plants can be mentioned as under:

1. Output level & efficiency matched the specifications of OEM. Average electrical efficiency was 33.8% against designed efficiency 36%.
2. Thermal efficiency was 40.1% against designed value 40%.
3. For load above 50 %, electrical efficiency was almost constant.
4. Power quality with respect to harmonic distortion was within acceptable limits.
5. Fuel Cell met steady state voltage specifications over 25% - 100% lower while power factor range was from 0.85 lagging to 0.95 leading.
6. Fuel cell transient response was within limits but softstarters are necessary for starting higher capacity motors.
7. Overall emission levels of NO_X, CO, CH_4 were within limits compared to designed parameters.

Parameter	Design Value	Actual Value	Unit
NO_x	0.02	0.002-0.004	Lb/MMBTU
CO	0.20	0.0004-0.009	Lb/MMBTU
CH_4	0.02	0.002-0.009	Lb/MMBTU

Economics :

Commercial viability of fuel cells was analyzed at 3 New York site considering a life cycle of 20 years. These installations being demonstration project are not economical in near term scenario.

1. For long term scenario the cost structure of 200 KW PC 25 is as follows :

Cost Component	Present Cost in USD	Future Cost in USD
Capital Cost	598000	299000
Installation & Commissioning	103450	51750
Maintenance Cost	0.25 /kWh	0.25/KWH
Stack Replacement Cost	103450	103450
Total Initial Cost	701450	350750

2. The life cycle cost analysis revealed that payback period is of the order of 13 years at present condition and can be reduced up to 6 years in future scenario.
3. Net present value of all the installations was negative.
4. Conclusion drawn from economic analysis are :

   - A prospective fuel cell installation should have favorable differential of conventional energy (gas/electricity).
   - Sale of electricity to electric supplies department at unfavorable rates to be avoided.
   - For minimizing the capital cost, expensive thermal recovery system is to be avoided.

Design Characteristics:

Model	ONSI –PC-25
Rated Power	200 KW
Output Voltage	480/277 Volt AC
Frequency	60 HZ
Generation Efficiency	36%
Fuel Gas Consumption Rate	1900 SCFH (at rated load)
Cell operating temperature	400^0 F
Cell operating pressure	Atmospheric
Heating up Time	5 Hrs
Location	Out door
Weight	61500 lb
Overall Dimension of power module	24 ft x 10 ft x 11.5 ft
Overall dimension of cooling module	12 ft x 6 ft x 7 ft

ii. MOLTEN CARBONATE FUEL CELLS:

The carbonate fuel cell promises highly efficient , cost effective, environmentally superior power generation from natural gas, coal gas, bio gas & other liquid fuels. FCE (formerly known as ERC) & M-C power have been engaged in the development of this unique technology focussing on the development of direct fuel cells (DFC). The DFC design incorporates the special internal reforming feature, which allows utilization of a hydrocarbon fuel directly in the fuel cell without involving any external reforming reactor and associated heat exchange equipment. Among the internal reforming options, FCE has selected the combination of indirect internal reforming (IIR) with direct internal reforming (DIR) as its base line design. In the IIR – DIR stack, a reforming unit (RU) is placed in between a group of fuel cells. The hydrocarbon fuel is first fed into the reforming unit, where it is reformed partially to hydrogen and carbon monoxide fuel using the available heat. The reformed gases are then fed to the DIR chamber, where the residual fuel is reformed simultaneously with the reactions of fuel cells. FCE plans to offer commercial DFC power plants in the MW level to be ideally suited for industrial co-generation, distributed generation & uninterrupted power supply (UPS) for military bases.

(a) Experience in Santa Clara :

FCE operated 2 MW plant in Santa Clara, California, the largest MCFC power plant till date and gained a lot of valuable experience. The city of Santa Clara received two national awards i.e. energy innovator award and technical achievement award for hosting and managing the first commercial demonstration of a MCFC power plant on a utility system in the world.

During the plant operation of initial 720 Hrs, the performance was excellent at power delivery upto 1.93 MW against rated capacity of 1.8MW. With auxiliary burners firing, the system efficiency met 44% against the target of 49%. Power quality with reference to voltage harmonics and current harmonics were below permissible levels (below 2%). Maximum ramp rate was 4.8%/Minute exceeding the target rate of 3.3%. Emissions with respect to SO_X & NO_X was undetectable and noise was less than that of an air conditioner (less than 60 dBA). The overall availability of the balance of plant during the test program was 99% and safety record was upto the mark.

However, the plant was shutdown on March'1997 for inspection after operation of about 5200 Hrs. The plant was operating at a temperature above 1000 Degree Fahrenheit and delivering 1710 MWH to the utility system of Santa Clara. The cause was the finding of transients in some of the stack voltages due to parasitic electrical circles. This phenomenon was due to breach of electrical isolation between fuel cell stacks and gas distribution piping. The source of these circuits was traced out to be a glue used to install the thermal insulation around the entry and exit process line to the fuel cell stacks. This glue failed at high temperature and caused the problem.

Power plant operations were resumed after repairing the dielectric components. The project demonstrated a Digital control system, which allows 16 stacks to be operated automatically. However in second operating period only 8 nos. unaffected stacks were put in the operation to generate 1.2 MW DC only. The most obvious lesson learnt was that such a plant could be assembled, transported & operated in a field environment. The plant output was controlled according to need and successfully separated form grid during grid disturbances temporarily.

(b) **Experience in San Diego :-**

250 MW NAS Miramar Molten Carbonate fuel cell demonstration is an integrated power plant consistent with M-C power's commercial development plan. The plant is located on the NAS Miramar military base near San Diego at an area of 3200 square feet and produces 340-640 lb/hrs steam at 100 PSI as well. The project first produced power on 24, Jan'1997. The quality of electricity and steam produced was excellent and transitions between on and off line were smooth. The project was a collaborative effort among San Diego gas and electric, M-C power, Bechtel Engineering and Institute of gas technology. During, the Phase I test, the demonstration plant operated for nearly 3000 hrs delivering about 16 MWH of electricity and 346000 lbs of steam to the grid of Naval air station. The maximum power output was 210KW and reason for such reduction in power was high pressure drop across the cathode. Currently, the plant is on a stand by mode awaiting system modifications based on the lessons from the Phase I test. The demonstration has proven that commercial cost target is achievable.

(c) **Experience in Japan :-**

In Japan the development of MCFC started in 1981 and it was planned to develop MCFC pilot plant of 1 MW class in 1987. It included 4 nos. 250 KW class stacks, a reformer, a turbine compressor, a heat recovery steam generator and so on. The pilot plant incorporated 2 nos. 500 KW class inverter and a cathode gas recycle blower for controlling stack temperature while recycling outlet gas to the inlet of the cathode. There were nitrogen, carbon-dioxide and hydrogen supply facilities in this plant, situated at Kawagoe thermal station of Chubu electric Power Company. Fuel used was LNG and electrical efficiency target was 45%. The plant will start operation by the end of 1999 although construction was complete by 1998.

iii) Proton exchange membrane fuel cells :-

Progress is reported towards the commercialization of PEMFC or solid polymer fuel cell (SPFC) both for transport and stationary applications. Ballard is in the middle of a four phase program to commercialize stationary PEMFC power plants of 250 KW range operating on natural gas by the year 2000. Ballard is also developing fuel cell stacks and power plants for a variety of transportation applications ranging from buses, automobiles, and sub-marines and surface ships. Ballard has started a program since 1990 to demonstrate zero-emission fuel cell powered buses. They have demonstrated a 40 feet long commercial air conditioned transit bus powered by 200 KW PEMFC. The bus has a range of 400 KM and uses hydrogen gas as fuel. Several auto makers like Daimler – Benz have also demonstrated small vans powered by MK 5 fuel cell stacks manufactured by Ballard. But in order to achieve widespread commercialization of fuel cells for transport application, current cost for equipment must be brought down to acceptable level. Fuel choice e.g. hydrogen or methanol used for fuel cell vehicle account for large hidden costs. A competitively priced fuel and a low cost fuel processor are essential for the successful market entry of such vehicle to compete with existing IC engines.

iv) Solid Oxide Fuel Cells :-

Westinghouse is developing its tubular solid oxide fuel cells (SOFC) for a variety of applications in stationary power generation market. Because of their high electrical efficiency (60-70%), SOFC products are initially expected to be integrated with gas turbines in the 1-7 MW range for emerging distributed generation market segment.

Westinghouse has demonstrated tubular SOFC of 25 KW range and operated for 13000 hrs. They have also experienced 8 year life demonstration on single cells and standardized 150cm^2 size fuel cells for commercialization. There commercialization steps include designing a 100 KW cogen system in Netherlands, and standardization of 500 KW modules to achieve seven MW range. It is expected that SOFC will make substantial progress by 2003 to be available at an installed cost of USD 1500/KW.

3.4 Visiting operating fuel cell power plants in North America:

As a participant of PEERS programme , the author got the opportunity to visit USA & Canada during October ,1999. Some operating fuel cell plants were visited in Danbury and New york to achieve first hand knowledge about the technology.

a) Interaction in Canada:

On 18/10/1999, the author visited the Department of Natural Resources, at Ottawa. Interaction was made with Dr. Martin Hammerli, Manager, Hydrogen and Fuel Cells regarding Canadian R&D programme on fuel cells.

It was learnt than Canada was specifically interested in R&D of PEMFC & SOFC type fuel cells. Two of the most notable successes in the Canadian hydrogen and fuel cell programme are the development in water electrolysis technology and Ballard's PEFC technology.

i) Water Electrolysis Technology:

Electrolyser Corporation has developed an electrolytic hydrogen plant, which permits the direct coupling of the solar photovoltaic array to the electrolyser. As a result, the world's 1st PY - Hydrogen vehicle filling station was designed by the company. A Company named Stuart Energy System Inc. is a leading supplier of hydrogen generators based on water electrolysis for refueling systems for fuel cell vehicles. The bus refueling station in Vancouver was opened in February'1999 to supply hydrogen to 3 nos. fuel cell buses being operated by the local transit authority.

ii) *Ballard's Fuel cell transit buses:*

Ballard Zero Emission Vehicle (ZEV) 120KW fuel cell bus was launched in 1995 using compressed hydrogen as fuel. Six nos. ZEV fuel cell buses are in operation by local transport authorities in Chicago and Vancouver. Dbb Fuel Cell Engines Inc. of Burnaby, British Columbia delivered the first fuel cell engine to Ford Motor Co., in September'1998. Test of the engine within P2000 prototype passenger car was successful. M/s. Ford Motor Co. & M/s. Daimler Chrysler are investing in Ballard's to commercially manufacture green cars by 2004. Ballard has also developed a prototype 250MW fuel cell power plant for stationary application. The Ballard fuel cell technology is suitable for distributed power generation and co-generation when fuelled by natural gas. Ballard has also developed state-of-the–art reformer and clean-up technology for the purpose.

b) *Interaction in Washington DC*

On 27/10/99, the author met Ms. Berni Geyer, Director, `fuel cell - 2000' an institution involved in publicity of latest developments in fuel cell technology. After discussion in details about scope of fuel cells in USA, it was learnt that USA Govt. is providing 35% subsidy to the consumers using fuel cell energy. Furthermore, the addressees of specific fuel cell installations were collected to arrange visits after completion of the `PEERS' programme.

During interaction with her, the following aspects regarding fuel cell were gathered.

- The potential fuel cell market will be about 3 billion dollars in USA within few years reducing trade deficit due to oil imports.
- The US department of energy spends about 50 million-dollars per year in R&D of MCFC & SOFC and 20 million dollars on transportation application of fuel cells.
- US faces fierce competition from other countries like Canada, Japan and Germany who are aggressively promoting fuel cell development with tax benefits, low interest loans and grants to reduce the costs.
- US DOE projects that if a mere 10% of automobiles nationwide were powered by fuel cells, regulated air pollutants would be cut by 1 million tons per year and 60 million tons of the greenhouse gas (Co2) emission would be eliminated.

- At present, fuel cell power plants are available at a cost of 3000 USD per kilowatt only for 'niche' markets. It is predicted that when fuel cell costs drop below 1500 dollar per kilowatt, they will achieve market penetration in US.
- Daimler Chrysler have pledged to make commercially viable fuel cell cars available by 2004.

c) Visit to PAFC power plant in New York:

On 30/10/1999, the author visited 200KW PAFC power plant at the police station building situated at Central Park, which is the heart of New York City. It was a joint venture by the DOE, US Govt. and New York power authority. The power plant was installed during March'1999 and is continuously in operation since then. The plant uses natural gas as fuel and meets power and hot water requirement of the complex.

The plant was supplied by ONSI Corporation, a subsidiary of International fuel Cells Corporation, Connecticut. The model was PC25C and rated at 200KW electrical output and 700000 Btu per hour thermal output. The power plant consumes 1900 standard cubic feet of natural gas per hour as fuel and in the form of package units called power module and cooling module.

Similar power plants have been installed at the Yonkers wastewater treatment plants in West Chester country, New York using an aerobic digester gas as fuel and office building at & Times Square in New York City. Discussion with the concerned in-charge at the police station revealed that the operating PAFC power plant was quite reliable as far as performance and availability of power is concerned.

d) Visit to MCFC Power plant at Danbury, Connecticut (USA):

On dated 01/11/1999, author visited Fuel Cell Energy Incl. at Danbury, a pioneer institutes involved in R&D and commercial manufacturing of MCFC type power plants. A day long interaction with Dr. Hansraj C. Maru, an Indian born scientist and vice president (advanced technology) and Mr. Joseph G. Mahler, Chief financial officer of the company revealed that the company has changed its name recently from Energy Research Corporation to Fuel Cell Energy due to the reason that the company has entered into manufacturing and marketing area from R&D with a view to commercialising MCFC power plants. New name FCE reflects the corporate mission of the company.

Initially, the author gave a presentation to the board of directors of FCE regarding the objective of the proposed project work.

Subsequently, Dr. H. C. Maru explained about the product range and R&D work of the company. Mr. Mahler replied about financial aspects and assured that megawatt class MCFC power plants will be commercially available by FCE at a cost of USdollar 1100/MW by the year 2004.

Dr. Hansraj Maru accompanied the author to the various laboratories, workshops, inside the premises including the operating 250KW MCFC power plant, which was meeting the energy need of the entire office complex. The plant had been working successfully for last one year and used natural gas as fuel. The following significant aspects were learnt during the visit.

- FCE set-up a demonstration MCFC plant of capacity 2MW at Santa Clara. California and a number of technical challenges were met successfully.
- The operating power plant visited by the author was a grid-connected commercial design of capacity 250KW.
- FCE has developed its products in three configurations e.g. 300KW, 1.5MW and 3MW to meet a variety of market needs.
- 300KW power plant is an ideal, skid-mounted, compact power plant designed for small consumers.
- 1.5MW and 3MW products are designed for larger demand profiles such as hotels, shopping centres, office buildings, industrial facilities or wastewater treatment plants.
- All three products offer the capability of co-generation where the product heat is suitable for high-pressure steam and air-conditioning.

- FCE, which has partners like Daimler Chrysler Corporation in Germany and Mitsubishi Electric Corporation in Japan, is committed to provide commercial power plant @ 1250 USD/KW by the year 2001.
- At natural gas cost US$2.5 / MMBtu (i.e. Rs. 3750/= per 1000 cubicmeter), cost of MCFC power is estimated to be 4.2 cents/KWH (i.e. Rs. 1.85/KWH). Since in India, cost of natural gas is presently Rs. 2000/= per 1000 cubic meter, the cost of electricity can be estimated to be about Rs. 1 / KWH at present. The technical specification of a 3 MW power plant to be commercially available by FCE shortly is given below for reference.

Typical 3 MW Power plant (MCFC)

DC Output	3200 KW
Fuel supply	Natural gas 558 M^3/hour
Electrical efficiency	57 %
Power plant heat rate	1507 Kcal/kwh 1673 Kcal/kwh
Voltage output	Site specific
Power quality	IEEE 519
Noise	60 dBA at 30 mtr. distance
Emission SO_x NO_x	0.001Kg./MWH 0.0002 Kg./MWH
Water discharge	553 lit./hour

Latest development of FCE is high efficiency hybrid power plant design, in which fuel cell waste heat is used to produce electricity is a non-combustion gas turbine cycle. The efficiency of these DFC /turbine hybrid power plants is expected to be above 70% . When DFC section produces 85% of the system power, remaining 15% is produced by turbine.

3.5 ASSESSMENT OF FUEL CELL TECHNOLOGY :-

In order to asses the available fuel cell technology for applications in Indian hydrocarbon sector for power generation, we have to think in a buyer's perspective keeping in view the various aspects like reliability, range, operation and maintenance and last but not least economic viability. Let us identify some criteria for analysis and assessments of the technology in systematic manner.

(i) Selection of applications :-

The following are some of the applications areas.

1. Group gathering stations (GGS) at small and marginal gas fields at Tripura, Karikal and Rajamundary of ONGC, where providing infrastructure for transportation of gas is not economical.
2. On site utilization at remote gas fields in Assam & Tripura by distributed generation and feeding power to local villages in forest area.
3. At intermediate compressor stations of cross country pipeline of HBJ project.
4. For instrumentation, illumination & telecommunication at 140 nos. unmanned well head platforms at Bombay offshore.
5. Co-generation at waste water treatment plants at Hazira & Uran project of ONGC using waste hydrocarbon as fuel.
6. In hill stations, where conventional power is expensive but space heating is essential due to low temperature environment. Co-generation from fuel cell can find its niche applications in areas like Mussorie, Simala and Darjeeling.

(ii) Preliminary Selection of Candidate Technology :-

In Indian conditions, we may introduce 200 KW range PC- 25C model, ONSI make phosphoric acid fuel cells as distributed generation for niche applications. However we may plan for early introduction of MCFC power plant either in ONGC or GAIL within a time frame keeping in view that commercialization is not far off from today.

(iii) Technical Evaluation of Suitability :-

Suitability of FC technology has to be adjudged on the basis of the following factors.

- Electricity and heat requirement of the utility system.

  For example – The fuel cell can be suitable for luxury hotels and hospitals situated at the heart of populous cities, where heat can be utilized for space heating & absorption type air conditioners and emission level as well as noise level are expected to be minimum.
- In chloro-alkali industries, hydrogen is a by product, which can be used as a fuel for fuel cell to generate power and process steam.
- Fuel cell plant can be used as standalone & grid connected mode for special applications. When surplus power is available, the same can be fed to grid during peak demand period.

(iv) Economic Assessment :

Recently, a project was completed to demonstrate 2MW MCFC power plant (designed for base load only) at Santa Clara, US with the cost of around $23000/KW. Plant has recorded operation more than 10,000 hrs successfully. Similarly there are a number of 250KW MCFC power plants installed throughout North America for power and heat purpose at various locations including San Diego & Danbury. No direct cost of MCFC is available commercially. A large number of expectations are made to find the cost effectiveness of MCFC technology in comparison to the present power generation technologies .Fuel Cell Energy Incl.(FCE) of US is planning to fabricate MCFC stacks with the cost of ranging from $1000/KW- $1500/KW by 2001 AD. Optimistically, it is expected that due to economy of scale, the cost will come down upto 1000$ / KW by the year 2004.

ECONOMICS OF DFC

- Power plant rating 3 MW
- Capital cost US $ 1250/KW
- When natural gas costs 2.5 $/MMBTU : Cost of electricity is 5.1 cents/kwh
- Stack replacement cost US$ 380/KW (at an interval of every 5 years)
- Balance of plant –30 years life
- Capital recovery factor-15%
- Load factor –95%
- O&M cost: Fixed -$21000/Year, Variable-$89000/year

India being a developing country, economic is not very accommodative to attract expensive fuel cell power. Unless the capital cost is acceptable to Indian market in comparison with available alternatives, fuel cell can't be popular. Stringent emission norms is a criterion favourable to fuel cell economics in USA. It is expected that emission norms in India will also follow the suit in near future, when fuel cell will draw more attention. Moreover, when MCFC and SOFC will be available commercially in more than 1.0 MW range, those will find application in heavy industrial co-generation at an acceptable cost say less than 1000 USD per KW.

COMPARISION OF POWER PLANT EMISSIONS (INDIAN SCENARIO)

Contaminant	*Gas fired 20 MW Turbine*	*2MW MCFC power plant at Santa clara*	*GPCB limits*
SO_X	5.5 PPM	0.1	100PPM
NO_X	11.64 PPM	2 PPM	50 PPM
SPM	10.87 MG/M^3	undetectable	150 MG/M3

APPLICATION OF FUEL CELLS

Sr. No.	Application	PAFC	PEMFC	MCFC	SOFC	AFC
1	Co generation	Yes	Yes	Yes	Yes	
2.	Utility Power	Yes		Yes	Yes	
3.	Distributed Power	Yes	Yes	Yes	Yes	
4.	Passenger Vehicles		Yes			Yes
5.	Heavy Duty Vehicles	Yes	Yes		Yes	
6.	Portable Power		Yes			
7.	Specialty Power (ups, space crafts)		Yes			Yes

4.1 Natural Gas Reserves

Natural gas is considered to be the most efficient source of energy during the present times. Natural gas consists mainly of the lower order paraffin hydrocarbon series like Methane (CH_4), Ethane (C_2H_6), Propane (C_3H_8), Butane (C_4H_{10}), and Pentane (C_5H_{12}) etc. While the first four are in gaseous state at normal temperature, pentane onwards are in the liquid state. Natural gas has a high percentage of methane, which together with ethane accounts for upto 96% of the total. The constituents of Indian natural gas are methane (77% - 88%), ethane (4% - 8%), n-butane, iso-butane, propane, hexane etc. (0.5% - 2%), carbon dioxide (2.2% - 8.4%) nitrogen (0.3% - 2%) and hydrogen sulphide (max. upto 180 ppm). Now-a-days LNG which is liquefied methane under very high compression and cooling (-160^{0}C) are considered one of the alternatives to domestic natural gas.

International pricing of natural gas is expressed in units like US$ /MMBTU, which is equivalent to Rs.1500/Thousand cubic meters. The following table lists the production , consumption and reserves to production ratio(R/P) for major producing/consuming regions of the world. It is observed that North America has a very low R/P ratio, although it has the highest production and consumption.

Natural Gas: World Statistics

Regions/Countries	*Production in bcm*	*Consumption in bcm*	*R/P ratio in years*
North America	735	740	11.5
Soviet block	623	493	86.2
Europe	276	417	19.5
Asia pacific	240	251	37.7
Middle East	167	159	>100
South &Central America	88	86	72.7
Africa	94	51	>1000
Total World	**2223**	**2197**	**64.1**
India	**24.4**	**24.4**	**22.9**
Pakistan	15.8	15.8	37.6
Bangladesh	7.9	7.5	39.1

Note:- The above data pertains to the year 1997.

Natural gas in India is produced by two major national oil companies i.e. ONGC & OIL and the contribution of the former is almost 95% of entire production quantity .An overview of natural gas production during 1997-98 in India is given at the following table.

Natural Gas Production(1997-98)

Natural gas field	*Production in bcm/year*
Bombay offshore	18.1
Gujarat onshore	3.1
Krishna Godavari &Cauvery basin	1.2
Assam	2.1
Tripura	0.2
Total	**24.7**

During 1998-99, ONGC has produced 23.97 bcm of natural gas alone, in which Hazira project of ONGC has a contribution of 10.5 bcm. The following table gives forecast for production of natural gas upto 2020.

Production Forecast (bcm/year)

Field	*Year-1998*	*Year-2005*	*Year-2020*
Bombay high	4.5	Decline	0.84
Bassein	10.9	Decline	7.90
Heera	0.4	Decline	0.06
Neelam	0.7	Decline	0.09
Tapti/Mukta/Panna	1.5	3.1	0.04
Gujarat	3.1	Decline	0.4
Assam	2.1	3.6	3.1
Others	1.5	Increase	2.57
Total	**24.7**	**22.0**	**15.0**
	Optimistic forecast	**22.0**	**33.0**
	Pessimistic forecast	**20.0**	**10.0**

According to Bechtel/ TERI forecast during 1998, the demand versus deficit of natural gas is given at the following table considering gas price Rs.5250/- per thousand cubic meters.

FORECASTS

Parameter	*1998*	*2002*	*2007*	*2012*	*2020*
Demand	28	36	52	74	95
Supply	23	25	20	16	13
Deficit	**5**	**11**	**32**	**58**	**82**

It is pertinent to mention here that gas pricing will get full parity with international price i.e. 3.5 US$/MMBTU by the year 2002. In spite of above deficit, it is envisaged that natural gas followed by LNG will continue to be more attractive for using as fuel for power plants compared to other competing fuel sources like coal. The reasons for advantage of natural gas as fuel in power sector are as follows.

1. High efficiency of power plants. (e.g. CCGT)
2. Environmentally clean. (NG has less quantity of pollutants like SO_X , NO_X & SPM and and 78% less greenhouse gas than coal)
3. Stable long term supply.
4. Low running cost of electricity.
5. Inland transportation of NG by pipeline is safe & economical.

From the above discussion, it can be summarised that:

1. Natural gas followed by LNG will play dominant role in fulfilling global energy demand especially power sector during the next half century.
2. In Indian context, though prospects of increased domestic production is slim, LNG from South- east Asia Pacific region will provide alternative to NG.
3. Last but not least, we should not forget that fuel cell power offers a sustainable approach to our NG resources, since it is the most efficient &

environment-friendly technology. Fuel cells will delay exhaustion of natural gas by ensuring its optimum efficient utilization.

4.2 REFORMERS:

Fossil fuel combustion currently contributes to over 75% of the total electricity generation in India. Fuel cells provide the most efficient means of converting the chemical energy of hydrogen to electricity. Hydrogen can be derived from fossil fuels e.g. coal , diesel or natural gas. Among the potential sources of hydrogen, natural gas offers many advantages. The reasons for preference of natural gas as fuel are that it is widely available , clean , and can be converted to hydrogen relatively easily.

The principle method of converting the natural gas to hydrogen are:-

1. Catalytic steam reforming
2. Chemical reduction of metal oxides
3. Thermal cracking
4. Partial oxidation
5. Internal reforming

Although the chemical composition of natural gas varies according to the source, the principal component is methane, the reminder being small amounts of hydrogen , nitrogen,CO_2 and sulphur. Natural gas is the cleanest of all fossil fuels and environmentally acceptable , in terms of its products of combustion. When catalytic steam reforming is used to generate hydrogen from natural gas , it is essential that sulphur contents in the natural gas are removed up stream of the reformer and various types of desulphurisation processes like high temperature desulphurisation & low temperature desulphurisation are available . Maximum permissible sulphur content in natural gas should be 0.2 PPM only. Low temperature cells (e.g. PAFC &AFC) do not tolerate concentrations of carbon mono oxide at their anodes. But the molten carbonate fuel cell and solid oxide fuel cell anodes contain nickel, for which CO can be oxidised electrochemically.

1. ***Steam reforming:-***

   The following reactions take place in equillibrium conditions at more than 500^0 C in the presence of a nickel catalyst.

   $CH_4 + H_2O = CO + 3H_2$

   $CO + H_2O = CO_2 + H_2$

   This is the cheapest and mature technology.

2. ***Chemical reduction of metal oxides :-***

   At temperature 900^0-1100^0 C range , gallium oxide can be reduced to the Gallium metal using methane.

   $CH_4 + Ga_2O_3 = 2Ga + 3Ca + 6H_2$

3. ***Thermal cracking : -***

   If methane or other hydrocarbons are heated in the absence of air , they will decompose to produce hydrogen and carbon.

   $CH_4 = C + H_2 - 18$ Kcal/ mol

   Although pure hydrogen can be obtained by this method, there is problem of disposal of the solid carbon as a by product.

4. ***Partial oxidation*: -**

   $CH_4 + 1/2\ O_2 = CO + 2H_2$

   Nickel may be used as a catalyst during this process. But, fuel cells using this process posses lower electrical generation efficiency compared to steam reforming.

5. *Internal Reforming*:-

The MCFC and SOFC , which operate at high temperatures allow natural gas to be reformed within the fuel cell stack. Internal reforming lowers the requirement for cell cooling and save in terms of capital cost. There are two basic internal reforming concepts e.g. Direct Internal Reforming (DIR) and Indirect Internal Reforming (IIR) . With DIR ,reforming takes place either directly on the anode or within the fuel channel of the cell. Heat and steam are supplied directly from the electrochemical reaction . The electrochemical reaction also helps to drive the reforming reaction to completion by removing the hydrogen as and when it is formed. DIR results in high conversion and high cell efficiencies. With IIR , the reforming reaction takes place in a compartment, which is in close thermal contact with the cell. This gives the advantage of good heat transfer from the cell in comparison with external reformers .The chemical reactions of internal reforming are similar to that of steam reforming. However, this is the latest method for reforming used for MCFC and SOFC.

(a) ***IRMCFC***: Initially, IIR-MCFC stacks were being developed by demonstration in North America. But now-a-days DIR-MCFC has become more popular due to a couple of reasons. Firstly, synergy of reformation and electrochemical reactions in terms of heat, steam and catalyst requirement gives higher efficiencies up to 58%. Secondly , lower capital cost of the MCFC power plant makes the technology more attractive. For example, Fuel Cell Energy Incl. at Danbury has developed such type MCFC power plants of 250 KW range and named them as DFC (Direct fuel cell) .

(b) *IRSOFC:* In the SOFC, the reforming of natural gas can be catalyzed by the nickel cermet anode material at 1000^0c . In cells running at low current densities(below 100mA/cm^2) the reforming reaction is not affected by the cell operation . Westinghouse, the pioneer company on SOFC have demonstrated that sulphur poisoning at the anode is a challenge to the technology. There is a greater propensity for carbon deposition in case of natural gas than methane as a fuel. Hence, current design have pre -

reformers located close to the stack. SOFC being the 3rd generation fuel cell , it can be expected that the existing problems of internal reforming will be sorted out by the time SOFC will find commercial use.

4.3 SELECTION OF POTENTIAL SITES FOR FUEL CELL APPLICATION :-

The basis of selection of potential sites in ONGC and GAIL was the factors like availability of natural gas, pipeline infrastructure, local demand of energy, accessibility of site, and cost & availability of conventional power. Since, PAFC upto 200KW capacity are presently available commercially, sites having energy demand upto 200 KW was identified. Secondly, locations were selected, where natural gas was easily available as fuel e.g. at offshore platforms and compressor stations across cross-country pipeline. Thirdly, fuel cell power being expensive, such locations were selected where conventional power was either not available or available at high cost. Keeping in view all these considerations, some potential applications in ONGC/GAIL are listed as under.

In ONGC, some potential sites for application of fuel cell based power are suggested as follows :

(i) In Bombay offshore, we have got about 140 nos. unmanned well head platforms, where DG sets of 20-50 KVA capacity are used to meet the power requirement for illumination, communication and instrumentation purpose. PAFC type fuel cells(40KW range) can be a good option at these installations. But, only 200KW units are available commercially. Hence, it may be planned for modification in future , when units at lower sizes will be available.

(ii) Remote valve stations en-route gas pipelines need power in the range of 25 KVA for meeting requirement of lighting, communication and cathodic protection system in ONGC. PAFC type fuel cells can be tried in place of DG sets or solar PV system.

(iii) In GAIL, the power requirement at remotely located compressor stations en-route HBJ pipeline is of the order of 200kw, which is met by Combined

Cycle Vapour Turbines for communication, lighting and instrumentation purpose, PC25A model of M/s. ONSI Corporation, USA may be a viable option.

(iv) Use of gas for power generation at remotely situated GGS near small & marginal gas fields can be planned by using PAFC of PC25A model of 200kw capacity.

DESCRIPTION OF SOME POTENTIAL SITES :

(A) ONGC :

A potential application of fuel cells is envisaged in Group Gathering Stations (GGS) at small and marginal gas fields at Tripura , Assam , Karikal and Rajamundry of ONGC , where providing infrastructure for transporation of gas is not economical. The author visited various drill sites and group gathering stations in Gandhar Project, Ankleshwar and made extensive discussions with the concerned production engineers and electrical engineers at the field level. Further more, the author also interacted with production engineers of Assam and Tripura Project to find out possible application sites for fuel cells.

(i) Upper Assam Project:

Group gathering stations are the centralised installations to collect mixture of oil and gas from different oil/ gas wells. These installations separate oil and gas so as to make those saleable.In Assam ,gas production is about 14 lacs cubic metres per day, out of which Lakwa field produces about 6 Lakhs cubic metres per day.

In Lakwa field , about 3.5 lacs cubic metres of gas per day is issued for gas lift system in order to build pressure to 55kg/cm2 from 6 kg/cm2. LKW/LKM oil field comprising an area of 70 square metres. Presently, 200 wells are in producing stage. This oil field comprises 9 nos group gathering stations (GGS) ,1 no central tank firm (CTF) , 2 nos gas compressor plants (GCP) and 4 nos water injection plants (WIP). Geographically , CTF,GGS-1 &GCP-1 are located at one complex in Lakwa , which is 20 kms away from Nazira , regional head quarter of ONGC and 40 km away from Sibsagar ,the district head quarter. The CTF is surrounded by other 8 group gathering stations.

In upper Assam field, about 8.5 cmd of gas is available for sale to GAIL,ASEB,HFCL and local tea estates.Each GGS has an electrical load of about 450 KW, which comprises oil despatch pumps-3x50 kw, low pressure gas compressors 4x75 kw, effluent treatment pumps 3x55 kw and other lighting & heating loads. The sources of power at these GGSs are:

GROUP GATHERING STATIONS IN UPPER ASSAM

SL. NO.	*LOCATION*	*MAIN POWER SOURCE*	*STANDBY POWER SOURCE*
1.	GGS-1	CPP / ASEB	250 KVA DG SET
2.	GGS-2	ASEB	250 KVA DG SET
3.	GGS-3	CPP / ASEB	250 KVA DG SET
4.	GGS-4	CPP / ASEB	250 KVA DG SET
5.	GGS-5	ASEB	250 KVA DG SET
6.	GGS-6	CPP / ASEB	250 KVA DG SET
7.	GGS-7	CPP / ASEB	250 KVA DG SET
8.	GGS-8	CPP / ASEB	250 KVA DG SET
9.	GGS-9	CPP / ASEB	250 KVA DG SET

Captive power plants(CPP) consist of 3 nos Gas turbines of 3 MW Capacity each, whereas contract demand from Assam State Electricity Board (ASEB) is of the order of 500 KVA. For each GGS.

It is pertinent to mention here that GGS-2 and GGS-5 are very remotely located inside the forest, where main source of power is unreliable ASEB supply. It is proposed to install commercially available 200 kw PAFC power plant at these GGSs initially. In later stage , the other GGSs can be taken up to replace ASEB supply by 200kw PAFC power plants. Planning can be made for the year 2004, when 3MW MCFC power plants can be introduced at CPP of new GGSs of similar nature.

In Gailkey and Rudrasagar oil field, there are 3 and 4 GGSs respectively of similar capacity, where source of power is ASEB \ DG set. These 7 GGSs are also identified for standby application of power by 200kw PAFC in place of DG sets.

(ii) Tripura Project :

Tripura project, Agartala is a natural gas field in ONGC producing about One Million of natural gas constituting C1(97-98 %), C2 (1%) and CO_2(0.2%). The project has 4nos GGSs situated at Konaban , Baramura ,Rokhia and Agartala dome (ADB) . The data with respect to production, capacity, electrical load , main/ standby power source is given in the following table.

TRIPURA PROJECT

SR. NO.	LOCATION OF GGS	PRODUCTION CAPACITY IN10^5SM^3/ DAY	ACTUAL PRODUCTION IN 10^5 SM^3/ DAY	ELECTRICAL LOAD IN KW	MAIN POWER SOURCE	STANDBY POWER SOURCE -1	STANDBY POWER SOURCE-2
1.	Konaban	5.0	3.5	119	TSES-300KVA	110KVA Gas engine-gen. set	63 KVA DG set
2.	Baramura	2.0	0.54	8.0	TSES-300KVA	63 KVA DG set	Nil
3.	Rokhia	5.0	4.0	1004	TSES-300KVA	120KVA Gas engine-gen. set	63 KVA DG set
4.	Agartala Dome	4.0	2.0	22	TSES-300KVA	125 KVA DG set	63 KVA DG set

In Tripura, GGSs are remotely located and logistically not approachable by railway lines. Roads are not designed for transportation of heavy machinery of power plants. Hence ,low- volume & low-weight portable fuel cells will be suitable for those locations .During his posting in Tripura project, the author has experienced that power supply by the state electricity department is quite unreliable and frequent tripping is order of the day. In this situation, 200kw PAFC or 300kw MCFC will certainly be viable options for main source of power. The former is already commercially available, whereas the later is going to be available by the end of current year.

(iii) Gandhar Project, Ankleswar:

At Gandhar Project , Ankleshwar, there are 6 nos GGSs producing about 0.5-0.6 million cubic metre of gas each at pressure about 1Kg/Cm2. The constituent of gas are Methane 85% , Ethane 4.5% , Propane 6% and Butane 2.5%.The calorific value is about 10000K calory /m3. Average electrical load at these GGSs is about 170 KW. There is an installation incorporating a CTF (Central tank firm) and LPG plant, where electrical load is about 600 KW including motive and lighting need. Main power source for LPG and CTF plant is 1000 KVA contract demand from Gujarat Electricity Board (GEB). There is no provision of standby power , since realiable power is available from GEB end. However ,63 KVA DG sets are used for providing standby power to critical loads at Group gathering stations. There is another installation called RPH (Refinery pump house), where contract demand of 750KVA is available from GEB. For entire complex of LPG+CTF +RPH a DFC power plant of rating 1.5 MW will be sufficient to replace the GEB power. However, this can be planned only during 2001, when DFC power plant will be commercially available at MW range. Similarly ,200 KW PAFC power plant can meet entire power requirement of Group gathering stations in place of GEB power. However , this proposal will be only attractive, when capital cost of fuel cells reduce further keeping in view reliability and easy availability of cheap GEBpower.

(B) GAIL:-

The author visited Hazira unit of Gas Authority of India Limited (GAIL) and interacted with the concerned engineers .It was found out that there is scope of application of fuel cells in Compressor Stations as well as Radio Repeater Stations across HBJ pipeline

(i) Compressor Stations:

In HBJ Project, there are 6 nos compressor stations including 2 nos additional units being installed recently. Main source of power is 2x2.7MW Gas turbines giving 6.6 KV out put. 1 unit is normally in operation , whereas the other unit is for stand by application. The second standby unit is a DG Set of 1350 KW capacity . The DG Set is of Taiyo , Japan make, Gas turbines are of Alison, USA make and Gas generators are of Brush , UK make. As third standby source,State Electricity Board supply (1000KVA Contract demand) is provided at all compressor stations due to strategic importance of installations . Natural gas pressure is reduced to 15 kg/cm^2 from 46 kg/cm^2 at these compressor stations. In new compressor stations, gas engines are being installed for standby application. The electrical running load in compressor stations is of the order of 2..3 MW,which includes 2 nos Fire water pumps of 185 KW each, 2 nos GREP (gas rehabilitation and expansion project) compressors of 700 KW each, 3 nos air conditioning plants of 100kw each, 3 nos instrument air compressors of 60 kw each and 10 nos lubrication pumps of 30 kw each . Hence 2 nos 1.5 MW range DFC power plants(MCFC) will be ideal choice for these compressor stations either for main source or standby source of power beyond 2001, when these plants will be commercially available. At least for new compressor stations, GAIL should consider for this energy option.

(ii) Radio Repeater Stations:

There are 55 nos Radio repeater Stations on the HBJ pipeline spreading across 5 states. These stations are used for communication purpose. The power supply used at these stations is called CCVT i.e. closed cycle vapour turbine. Rated output is of 2.5 KW at voltage level 48 volts D.C. Each station has 2 nos CCVT, so that totally 110 nos CCVTs are installed across HBJ pipeline to provide power for the purpose of instrumentation, communication and cathodic protection system. Emergency power back up is given by battery bank of 600 AH (Nickel-Cadmium cells) capacity.

The CCVT is based on the thermo-dynamic Rankine cycle principle. The major components are vapour generator , turbo alternator , condenser and combustion system. It is a single hermetically, sealed system containing an organic motive fluid called chlorobenzone (C_6H_5Cl).
The gas fired burner heats the organic fluid contained in the vapour generator. As the liquid vapourises, it flows up the turbine vapour inlet tube to the turbine wheel , where it produces rotational shaft power to drive the alternator. The vapor then passes in to the condenser , and is converted in to liquid state. The cooled liquid motive fluid cools the station and supports the rotor of alternator within the fluid film bearings. The cycle continues as long as heat is applied to the vapour generator and is removed by the condenser.

As the entire motive fluid system is hermetically sealed, none of the organic fluid is lost in the process.The turbo alternator opeartes in a hermetically sealed stain less steel envelope and has only one moving part i.e. the rotor. The turbo generator provides 3 phase A.C. power, which is rectified and filtered. The DC out put is regulated according to varying load. The amount of gas fuel supplied to the burner automatically controls the heat input of the system and in turn generates electricity. The system has foolproof protection and rated for 20 years of life. The model available is 25 AG-48 , which produces 48 VDC, consumes 81 cubic metre /hr of natural gas and uses 233 lits of motive organic fluid.

This CCVT system is being used at the Radio repeator stations since 1987,when the capital cost was about Rs 40 lacs. It was gathered from discussion that present cost of the system is around Rs 1 Crore .Recently,some of the canisters of turbo alternator have gone defective and need to be replaced at a replacement cost of Rs20lacs.

Keeping in view all these conditions, it is suggested that PAFC power of capacity 2 .5KW will be commercially viable to be used at the repeater stations. The cost of 2.5 KW PAFC will be less than Rs5 Lacs, which is quite economical compared to replacement of canister in the existing system , which costs about 20 Lakh. Moreover, there is no need of rectification of AC to DC , since fuel cell generate DC directly .But the problem is that PAFC of this range is not commercially available in the market. Hence, it is suggested that organisations like TERI/ BHEL may develop PAFC up to 5 KW range for suitable application in GAIL.

5.1 SUMMARY

After all above deliberations, we may summarize the study conducted on the subject as follows.

- Fuel cell for power generation is an established technology.
- It is clean & most efficient mode of power generation.
- Efficiency ranging 50% -60% in single cycle and upto 72% in hybrid cycle have been projected.
- Fuel cells have been successfully used in space applications.
- Power plants of 200KW are commercialized and of 1.5MW are under development & testing and expected by 2001.
- There is a need of identification of potential applications and sites for early introduction of this technology in India.
- It is recommended that ONGC & GAIL may keep in touch with this emerging technology for early application in niche areas of natural gas sector . Some of the suitable sites are given at the following table.

SOME RECOMMENDED POTENTIAL SITES

SL. NO.	*SELECTED SITE LOCATIONS*	*NO. OF SITES*	*POWER REQUIREMEN*	*PROPOSED TYPE OF FUEL CELL*	*REMARKS*
1.	Group Gathering Stations at ONGC,Assam	20	3MW(main) 200KW(standby)	2x1..5MW MCFC 200KW PAFC	MCFC of this range will be commercially available in 2001.
2.	Group Gathering Stations at ONGC,Tripura	4	250KW(main)	200KW PAFC /300KW MCFC	Both are commercially available
3.	Well –head Platforms in Mumbai offshore, ONGC	140	25KW	25KW PAFC	Commercially not available in this range. To be developed
4.	Compressor stations on HBJ pipeline, GAIL	6	2.3MW AC	2x1..5MW MCFC	MCFC of this range will be commercially available in 2001
5.	Radio Repeater Stations, GAIL	55	2.5KW DC	2.5KW PAFC	Commercially not available in this range. To be developed

Implementation strategy in ONGC

In new millenium, ONGC has modified its vision to become a global energy company with the following initiatives in the direction of diversification in energy sector.

1. ONGC is one of the promoters of Petronet LNG limited , which has been set up for import and utilisation of LNG in India. ONGC has already signed MOU with various potential end users.
2. A 360 MW combined cycle dual fuel power plant (a joint venture with NTPC) is being set up at Hazira project, for which draft feasibility report has already been approved and the project is likely to be completed by 2002 at a capital cost of Rs 1150 crores
3. ONGC has identified a 300KW gasification combined cycle power plant to be set up at Panipat in participation with IOC.

In this changed scenario , fuel cell will be a future option for diversification for this company.

As an implementation strategy, a presentation titled "Fuel cell technology as an energy option for power generation " was given by the author at " ONGC Technology Meet" held in Chennai during November 1999 for appraisal of top management and other delegates. During this meet Director (Technical),ONGC declared in his speech that fuel cell technology has the biggest market in India during the current decade. Another presentation regarding fuel cells was also given to CMD,ONGC, who showed keen interest for this new energy option. However, it was suggested to wait till 2001 for implementation in ONGC, keeping in view the fact that technology will be more mature and cheaper in due course. In this contest, some potential sites have been identified by the author to introduce fuel cells in logistically remote locations in ONGC.

The contribution achieved from this project can be summed up as follows :

1. First hand assessment of FC technology for Indian conditions based upon the experience gained at developed countries.
2. Identification of potential application and sites in the natural gas sector for early introduction at niche area.
3. Economic assessment of a new, more efficient but commercially immature technology at present cost and with projected costs.

   The aspects which have been taken into account for this purpose are overall efficiency, power/heat ratio, comparison of cost of electricity with alternatives, comparison of cost of steam with alternatives, cost of transporting gas, site specific features and emissions etc.

4. Exploring possible options for diversification of corporate activities.

   For example – ONGC can diversify to production of methanol which will be used in fuel cell vehicles. GAIL or ONGC can setup integrated captive power plants and produce electricity and steam as well. Electricity can be sold to the national grid or other neighboring industries to earn revenue in liberalized economy

5.2 CONCLUSION :-

The future market of fuel cell will be mainly dictated by the acceptable cost of the product, in combination with environmental regulations. However, their considerable development potential in comparison with existing as well as competing technologies and the transition from low volume & high cost to high volume & low cost production can make fuel cells a serious contender for the next decade.

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